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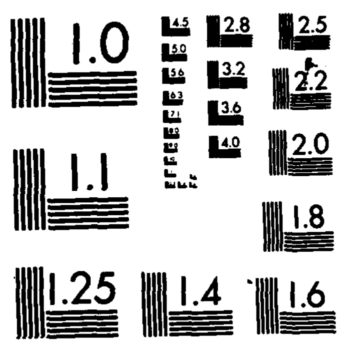

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ACTIVE AND PASSIVE REMOTE SENSING OF ICE

Department of the Navy
Office of Naval Research
Contract N00014-83-K-0258

SEMI-ANNUAL REPORTS

covering the period

February 1, 1985 - July 31, 1985

prepared by

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July 1985

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ACTIVE AND PASSIVE REMOTE SENSING OF ICE

Principal Investigator: Jin Au Kong

SEMI-ANNUAL PROGRESS REPORT

This is a progress report for the study of active and passive remote sensing of ice performed during the period of February 1, 1985 - July 31, 1985 under the sponsorship of ONR Contract N00014-83-K-0258. During this period we have: (1) developed a two-layer anisotropic random medium model to exploit the anisotropic effect of sea ice for active and passive microwave remote sensing, (2) used the Feynman diagrammatic technique in selectively summing an infinite perturbation series to include multiple scattering effects due to secularities that occur in the series for long-distance propagation, (3) extended the study of the two-layer anisotropic random medium model to a layer of isotropic random medium on top of a layer of anisotropic random medium in order to simulate the snow-covered ice fields for active microwave remote sensing, (4) used the strong fluctuation theory and the fluctuation-dissipation theorem to calculate the brightness temperatures from a bounded layer of random discrete scatterers with the zeroth and first order approximations, and (5) participated in the microwave sea ice measurement program at the Cold Regions Research and Engineering Laboratory (CRREL) in New Hampshire.

The electrical anisotropy of sea ice has been attributed to the preferred orientation of c-axis in the horizontal plane, which is aligned parallel to the 'long-term' current direction at the ice/water interface. The radar scatterometer measurements of sea ice also strongly suggest a theoretical model with an anisotropic permittivity tensor. Based upon the proposition that the large cross-polarization components as measured in sea ice is a first order effect, we have developed a two-layer anisotropic random medium to account for the volume scattering effects and the anisotropic effect of sea ice. The dyadic Green's function for a two-layer anisotropic medium is first derived and approximated for the far field. The random permittivity fluctuation is then characterized by three correlation functions: (a) the autocorrelation between azimuthal fluctuations at two different spatial points, (b) the autocorrelation between vertical fluctuations at two points, and (c) the cross-correlation between azimuthal and vertical fluctuations at two points. With the known shape of the fluctuation structure, the third correlation function is related to the first two. The first order backscattering coefficients are calculated with the Born approximation for active microwave remote sensing. The results are examined and interpreted, emphasizing the effect of anisotropy of the random permittivity on the backscattering coefficients that include cross-polarization, as a function of frequency, incidence angle, incidence azimuthal angle, and tilted angle of the optic axis. The theoretical model is shown to correspond to the ellipsoidal discrete model, which also enables us to determine the relationship between the cross-correlation and autocorrelation functions. Finally the theoretical results are used to analyze the experimental data obtained from sea ice measurements. In passive microwave remote sensing, the principle of reciprocity is invoked to calculate the brightness temperatures of a two-layer anisotropic random medium. The bistatic scattering coefficients are first computed with the Born approximation. Then, we integrate it over the upper hemisphere and subtract it from unity to obtain the emissivity for the random medium layer. The angular responses of the emissivities are illustrated numerically for studying their dependence on the variance, the correlation lengths, and the mean permittivities, all of which can be anisotropic. It is shown in both theory and actual controlled field measurements that both the absorptive and randomly fluctuating properties of the anisotropic medium can affect the behavior of the resulting brightness temperatures. When and if such ground truth is available for sea ice measurements, the theoretical model is ideal for interpretation of the experimental data since sea ice is also a highly anisotropic random medium. It is expected that the radiometric data from the CRREL measurements can also be successfully interpreted with this theoretical model.

For electromagnetic wave propagation and scattering in an anisotropic random medium, we have derived the Dyson equation for the mean field, and the Bethe-Salpeter equation for the correlation or the covariance of the field. With the random permittivity expressed in a general anisotropic form, the bilocal and the nonlinear approximations are employed to solve the Dyson equation and the ladder approximation to the Bethe-Salpeter equation. The mean dyadic Green's function for a two-layer anisotropic random medium with arbitrary three-dimensional correlation functions has been investigated with the zeroth-order solutions to the Dyson equation under the nonlinear approximation. The effective propagation constants are calculated for the four characteristic waves associated with the coherent vector fields propagating in an anisotropic random medium layer, which are the ordinary and extraordinary waves with upward and downward propagating vectors respectively.

Following up the success of the two-layer anisotropic random medium model in data matching and scene interpretation, we have also developed a three-layer model for snow-covered ice fields with snow simulated by an isotropic random medium layer and sea ice by an anisotropic random medium layer. We derive the dyadic Green's functions for the three-layer medium, characterize the volume scattering by the random fluctuations of the permittivities, and apply the Born approximation technique to calculate the scattered electromagnetic intensities for an incident radar signal. The backscattering cross sections are computed for active microwave remote sensing. This general theoretical approach can be extended to calculate the bistatic scattering coefficients. After integrating the bistatic scattering coefficients over the upper hemisphere and subtracting it from unity, we can also compute the radiometric brightness temperatures for passive microwave remote sensing by invoking the principle of reciprocity. The correlation functions are assumed to be Gaussian laterally and exponential vertically for both snow and ice. The average physical sizes and the volume scattering strengths of the ice particles and the brine inclusions are characterized by the corresponding correlation lengths and normalized variances respectively. The application of theoretical results is illustrated in data matching.

For passive microwave remote sensing of snowpacks, we have applied the strong fluctuation theory in conjunction with the fluctuation-dissipation theorem to calculate the brightness temperatures for a bounded layer of random discrete scatterers. The effective permittivity of a random medium with strong permittivity fluctuations is evaluated by properly taking into account the singularity of dyadic Green's function. The coherent and incoherent bistatic scattering coefficients are calculated with the distorted Born approximation. Then, the coherent and incoherent reflectivities are obtained by integrating the bistatic scattering coefficients over the upper hemisphere and the emissivity e is given by $e = 1 - r$. Various functional dependences on wavelength, polarization, observation angle, medium depth, scatterer constituents, and other physical parameters are illustrated in fitting the experimental data for snowpacks. This theoretical model is shown to be very useful in the interpretation of the microwave thermal emission data from, for instance, snowpack with ice layers where volume scattering effects due to medium inhomogeneities and interference effects due to layering play the dominant roles.

During the winter microwave remote sensing program at CRREL, we have carried out several measurements and observations on the radar return from the artificial sea ice and the artificially added snow layer on top of the sea ice with prepared salinity 24 *o/oo*. A radiometer was operated in the frequency range of $4 \sim 8$ GHz, with the increment step 100 MHz for the passive microwave experiments. The lossy behavior of the artificial sea ice was also found. In active microwave measurement, a scatterometer with scan range of $0° \sim 50°$ was used to measure the returns of linearly polarized radar signals at three frequency ranges of C, X, and KU bands. It was found that the artificial sea ice was highly lossy and the backscattering cross sections dropped for about 4 dB when the incidence angle was changed from 0° to 20°. The backscattering cross sections per unit area for VV polarization as a function of angle were collected on March 8, 1985 for both bare and snow-covered sea ice. The enhancement due to the snow layer on top of the sea ice was seen. The experimental data of the snow-covered sea ice have been analyzed by our three-layer model with the top layer represented by an isotropic random medium, the middle layer by an anisotropic random medium, and the bottom layer by a homogeneous medium.

PUBLICATIONS SPONSORED BY ONR

A. Journals

A1. "Dyadic Green's functions for layered anisotropic medium," (J. K. Lee and J. A. Kong), Electromagnetics, 3, 111-130, 1983.

A2. "Wave approach to brightness temperature from a bounded layer of random discrete scatterers," (Y. Q. Jin), accepted for publication in Electromagnetics.

A3. "Ladder and cross terms in second order distorted Born approximation," (Y. Q. Jin and J. A. Kong), accepted for publication in J. Mathematical Physics.

A4. "Active microwave remote sensing of an anisotropic random medium layer," (J. K. Lee and J. A. Kong), accepted for publication in IEEE Trans. on Geoscience and Remote Sensing.

A5. "Passive microwave remote sensing of an anisotropic random medium layer," (J. K. Lee and J. A. Kong), accepted for publication in IEEE Trans. on Geoscience and Remote Sensing.

A6. "Electromagnetic wave scattering in a two-layer anisotropic random medium," (J. K. Lee and J. A. Kong), Optical Society of America, 1985

B. Technical Reports

B1. "Active microwave remote sensing of an anisotropic random medium layer," (J. K. Lee and J. A. Kong), Technical Report No. EWT-RS-68-8407, M.I.T., 1984.

B2. "Ladder and cross terms in second order distorted born approximation," (Y. Q. Jin and J. A. Kong), Technical Report No. EWT-RS-71-8412, M.I.T., 1984.

B3. "Passive microwave remote sensing of an anisotropic random medium layer," (J. K. Lee and J. A. Kong), Technical Report No. EWT-RS-72-8412, M.I.T., 1984.

B4. "Wave approach to brightness temperature from a bounded layer of random discrete scatterers," (Y. Q. Jin), Technical Report No. EWT-RS-73-8412, M.I.T., 1984.

B5. "Electromagnetic wave scattering in a two-layer anisotropic random medium," (J. K. Lee and J. A. Kong), Technical Report No. EWT-RS-74-8506, M.I.T., 1985.

B6. "Radar backscattering from snow-covered ice," (F. C. Lin, J. K. Lee, J. A. Kong, and R. T. Shin), Technical Report No. EWT-RS-75-8508, M.I.T., 1985.

C. Conference Articles

C1. "Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers," (L. Tsang and J. A. Kong), IEEE/APS Symposium and URSI Meeting, Houston, Texas, May 23-26, 1983.

C2. "Theory of microwave remote sensing of dense medium," (L. Tsang and J. A. Kong), IEEE/GRS Symposium and URSI Meeting, San Francisco, September 1983.

C3. "Wave scattering by a bounded layer of random discrete scatterers," (Y. Q. Jin and J. A. Kong), URSI Symposium, Boulder, Colorado, January 11-14, 1984.

C4. "Active and passive microwave remote sensing of layered anisotropic random medium," (J. K. Lee and J. A. Kong), National Radio Science Meeting, Boston, Massachusetts, June 25-28, 1984.

C5. "Strong fluctuation theory of random medium and applications in remote sensing," (Y. Q. Jin and J. A. Kong), International Symposium on Antennas and EM Theory (ISAE), Beijing, China. August 24-26, 1984.

C6. "Radar backscattering from snow-covered ice," (F. C. Lin, J. K. Lee, J. A. Kong, and R. T. Shin), Proceedings Snow Symposium V, Hanover, New Hampshire, August 13-15, 1985.

C7. "Mean dyadic Green's function for a two-layer anisotropic random medium : nonlinear approximation to the Dyson equation," (J. K. Lee and J. A. Kong), International Symposium on Antennas and Propagation, Kyoto, Japan August 20-22, 1985.

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